

I. INTRODUCTION
The Global Agriculture Monitoring (GLAM) Project aims to enhance the agricultural monitoring and crop production estimation capabilities of the USDA Foreign Agricultural Service (USDA/FAS) using NASA's moderate resolution satellite data. The project is a collaboration between NASA/GSFC, USDA/FAS, and University of Maryland College Park (UMD) Department of Geography, in the framework of a joint NASA/USDA MOU to foster increased cooperation between the two agencies.

The primary mission of the FAS is to provide agricultural information for global food security through delivery of objective, timely and regular assessments of global agricultural production outlook and the conditions affecting it. To meet its objectives, the FAS uses satellite data and products to monitor agriculture and to locate and keep track of the climatic factors that impair agricultural productivity such as short and long-term droughts, floods, and persistent snow cover. These data are used to augment regional field-based reporting and help in the decision-making process.

To monitor crop conditions, the FAS analysts are provided with multiple remotely sensed products from moderate resolution sensors for target agricultural regions worldwide. This includes providing USDA crop analysts with a sophisticated web interface for analyzing MODIS temporal composites of vegetation index (VI) data, at 250-meter resolution. The web interface provides analysis tools which allow the crop analysts to drill down to the pixel level of detail. Using these data and tools, FAS analysts track the evolution of the growing season and make inter-annual comparisons of season dynamics between individual years as well as relative to reference long-term mean conditions. These comparisons yield anomaly images and plots that highlight regions that are less productive relative to previous years due for example to drought and heat stress as well as regions that experienced favorable climatic conditions and thus are more productive. For instance, this year eastern Africa experienced a severe drought leaving millions in need of food aid. Using the VI time series and web analysis tools FAS analysts tracked this drought and its effects on agricultural lands forewarning the appropriate decision makers of the crisis. For near real time assessment and evaluation of disaster events such as floods FAS analysts have access to daily global data through the MODIS Rapid Response system which delivers data within 2-4 hours of satellite acquisition.

II. Project Background Mission and Goals

Project Background NASA/USDA MOU

The Application of NASA EOS MODIS Data to FAS Agricultural Assessment and Forecasting

To meet its objectives, FAS/PECAD uses satellite data and data products to monitor agriculture worldwide and to locate and keep track of natural disasters such as short and long term droughts, floods and persistent snow cover which impair agricultural productivity. FAS is the largest user of satellite imagery in the non-military sector of the U.S. Government. For the last 20 years FAS has used a combination of Landsat and NOAA-AVHRR satellite data to monitor crop condition and report on episodic events.

FAS is upgrading and enhancing the satellite component of its PECAD decision support system through an information delivery system for MODIS data and derived products. NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) on board two platforms of the Earth Observing System (EOS), was designed in part to monitor subtle vegetation responses to stress, vegetation production, and land cover, with regional-to-global coverage. Hence, integration of MODIS data and derived products into the PECAD FAS DSS provides FAS with better characterization of land surface conditions at the regional scale and enables monitoring of changes in the key agricultural areas of FAS focus regions in a more timely fashion and at a higher resolution than previously possible with NOAA-AVHRR data.

MODIS: An Operational Prototype

Although MODIS is a NASA experimental mission, the instrument's capabilities will be extended by the launch of the Visible Infrared Imaging Radiometer Suite (VIIRS) in 2008, part of the National Polar Orbiting Environmental Satellite System (NPOESS), which will become fully operational in 2009. Thus the methods and system developed through this research project can be transitioned into a fully operational domain.

PECAD's Scope

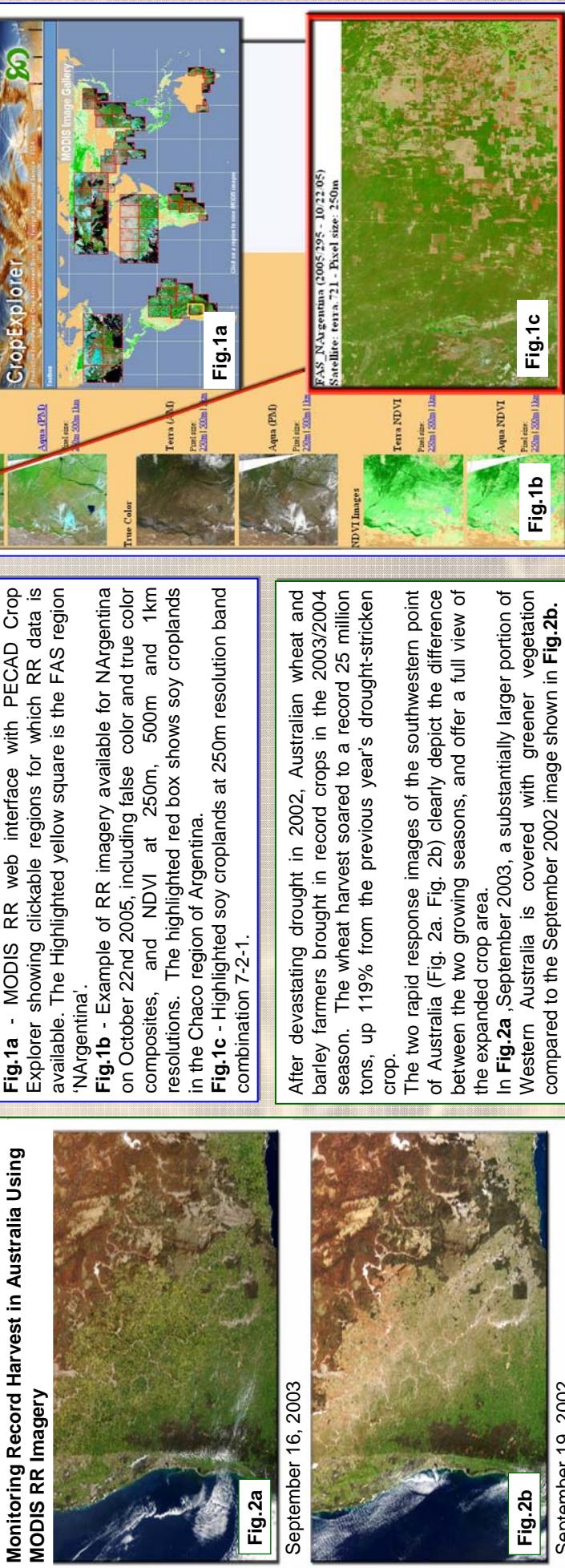
The FAS, through PECAD, provides agricultural information for global food security. It produces objective, timely and regular assessments of global agricultural production outlook and the conditions affecting food security. PECAD is responsible for global crop condition assessments and estimates of production and yield of grains, oilseeds, and cotton. PECAD assessments are an integral component of the monthly crop analysis reports issued by USDA's World Agricultural Outlook Board - a primary source for agricultural information worldwide.

III. Project Components:

- Delivery and integration of MODIS Rapid Response (RR) system provides rapid access to MODIS data collected twice daily from the Terra satellite in the morning (10:30am) and the Aqua satellite in the afternoon (2:30pm). The RR system provides FAS analysts with access to georeferenced, calibrated, mosaiced daily global MODIS imagery for FAS regions of interest within 2-4 hours of satellite acquisition. RR data are available to FAS analysts at spatial resolutions of 250m, 500m and 1km in different band combinations. Such rapidly accessible data allows the FAS analysts to evaluate, and assess, in near real time, the effect of disaster events on crops.
- Development and delivery of a long term database of MODIS composite Vegetation Index (VI) time series including analysis tools and a graphic user interface that provides mosaicking, reprojection capabilities, and easy access to the moderate resolution image archive.
- Establishment of the relationship between MODIS VI data and the long-term archives from the AVHRR and SPOT-VEGETATION used by FAS/PECAD.
- Development of enhanced MODIS cropland products including a crop mask, a crop type map, new band combination products, and a crop stress index.

A. MODIS Rapid Response

The MODIS RR web interface with PECAD Crop Explorer



B. Long-Term Monitoring: An inter-sensor Calibration

The Global Inventory Monitoring and Modelling Studies (GIMMS) group at NASA Goddard Space Flight Center (NASA/GSFC) provides spot NDVI data stream of NDVI that spans over two decades (1981-present). The GIMMS NDVI is derived from measurements made by the Advanced Very High Resolution Radiometer (AVHRR), Global Area Coverage (GAC) data from the National Atmospheric Oceanic Administration (NOAA) polar orbiting series of satellites. GIMMS has inter-calibrated the data from the NOAA-AVHRR satellite series and performed atmospheric correction to minimize the effects of volcanic aerosols to produce the consistent multi-source long-term data record for agricultural monitoring. This allows FAS analysts to compare current data with the spatial extent and severity of NDVI anomalies associated with heat stress, droughts and floods associated with crop failures. VIs from different sensors are related by examining their temporal and spatial behavior (means, ranges, and anomalies) at target FAS agricultural regions throughout the globe and interpreting these statistical patterns with respect to the growing seasons for various crops. The aim of this project component is to build a consistent time series that best represents the vegetation dynamics over these agricultural regions.

C. Long Term Database of MODIS Composite Vegetation Index Time Series
In monitoring crop conditions for a specific region, remotely sensed vegetation index data are used to track the evolution of the growing season compared to the reference long-term mean conditions. A global normalized difference vegetation index (NDVI) is produced from MODIS data, and is referred to as the "continuity index" similar to the existing archive of NOAA-AVHRR derived NDVI.

A global NDVI time-series database, with a spatial resolution of 250 meters has been assembled using a 16-day compositing period, allowing for interannual comparisons of growing season dynamics. This MODIS NDVI dataset is automatically re-projected and mosaicked to suit the FAS regions of interest. The time-series data are accessible to FAS analysts through a powerful web interface and analysis tool. From this stand-alone interface the analysts can query these data by pre-defined sub-regions, by interactive regional subsetting, and by implementing crop/water masks to:

- plot time-series graphs over the crop growing seasons to quickly assess crop conditions and anomalies.
- view spatially NDVI anomalies comparing current conditions to previous year, or historical mean.
- plot histograms of current and historical NDVI data.
- These data and utilities are fundamental for crop yield forecasts and can serve as an early warning system for regions suffering from crop loss and food shortages.

Tracking Drought in the 2004-05 Growing Season using the USDA/FAS MODIS DBMS

B1. Kenyan drought depicted by the MODIS time series web interface

Tracking Drought in Kenya

Kenya experienced a severe drought in Jan 2005 leaving up to 2.7 million people in need of food aid. Using the MODIS composite NDVI time series and analysis tools, available through the web interface, FAS analysts tracked this drought and its effects on agricultural lands.

B2. Tracking the Iberian Peninsula Drought in the 2004-05 Growing Season

Spain is suffering its worst drought since records began in 1943, and Portugal is experiencing its worst drought since 1940. The U.S. Department of Agriculture's Foreign

Agricultural Service estimated rainfall totals for both Spain and Portugal to be as much as 75 percent below average between September and February reducing yields to almost

The impact of the dry weather on vegetation is shown in Figures 4a – 4d.

Fig. 1a - NDVI - Jan 1st - 16th 2005

Fig. 1a - NDVI composite Jan 1st - 16th 2005 Greens correlate to increasingly higher NDVI values indicative of increasing green vegetation, browns correlate to lower NDVI values.

Fig. 1b - NDVI - Jun 9th - Jun 25th 2005

Fig. 1b - NDVI anomaly image: Jan 1st - 16th 2005 versus the mean NDVI for this time-step between 2000 and 2004. Red/brown indicate lower than the multi-year mean NDVI values. Greens indicate higher than mean NDVI values.

Fig. 1c - NDVI - Jun 9th - Jun 25th 2005

Fig. 1c - NDVI versus the mean NDVI for this time step. Showing a worsening of drought conditions especially in southern Kenya. The highlighted blue box shows an affected corn growing region within the Eastern Province, and the highlighted red box shows an affected wheat growing region within the Western Province.

Fig. 1d - NDVI - Jun 9th - Jun 25th 2005

Fig. 1d - NDVI anomaly image: Jan 17th - Feb 1st 2005 versus the mean NDVI for this time-step between 2000 and 2004. The highlighted crop region in Castile-León shows highly reduced NDVI values. The red line consistently below the green line indicates highly reduced NDVI values throughout the season, due to the severe drought.

Fig. 2a - Zoom-in to affected wheat region in the Eastern Province

Fig. 2a - Zoom-in to an affected corn region in the Eastern Province showing NDVI anomalies for crop pixels.

Fig. 2b - Zoom-in to affected wheat region in the Western Province

Fig. 2b - Zoom-in to an affected wheat region in the Western Province. The red line, consistently lower than the others, depicts the 2004-05 season exhibiting the effects of the drought on this region.

Fig. 2c - Histograms for the Jan 17th - Feb 1st time-step for years 2000-2005 for the highlighted corn region

Fig. 2c - Histograms for the Jan 17th - Feb 1st time-step for years 2000-2005 for the highlighted corn region shows that the NDVI values for 2005 were lower than the previous years.

Fig. 2d - Zoom-in to affected wheat region in the Western Province

Fig. 2d - Zoom-in to an affected wheat region in the Western Province. The red line, consistently lower than the others, depicts the 2004-05 season exhibiting the effects of the drought on this region.

Fig. 3a - Zoom-in to affected wheat region in the Western Province

Fig. 3a - Zoom-in to an affected wheat region in the Western Province. The red line, consistently lower than the others, depicts the 2004-05 season exhibiting the effects of the drought on this region.

Fig. 3b - Zoom-in to affected wheat region in the Western Province

Fig. 3b - Zoom-in to an affected wheat region in the Western Province. The red line, consistently lower than the others, depicts the 2004-05 season exhibiting the effects of the drought on this region.

Fig. 3c - Zoom-in to affected wheat region in the Western Province

Fig. 3c - Zoom-in to an affected wheat region in the Western Province. The red line, consistently lower than the others, depicts the 2004-05 season exhibiting the effects of the drought on this region.

Fig. 3d - Zoom-in to affected wheat region in the Western Province

Fig. 3d - Zoom-in to an affected wheat region in the Western Province. The red line, consistently lower than the others, depicts the 2004-05 season exhibiting the effects of the drought on this region.

Fig. 4a - NDVI - Jan 1st - 16th 2005

Fig. 4a - NDVI composite Jan 1st - 16th 2005 Greens correlate to increasingly higher NDVI values indicative of increasing green vegetation, browns correlate to lower NDVI values.

Fig. 4b - NDVI - Jun 9th - Jun 25th 2005

Fig. 4b - NDVI anomaly image: Jun 9th - Jun 25th 2005 versus the mean NDVI for this time-step between 2000 and 2004. The highlighted crop region in Castile-León shows highly reduced NDVI values. The red line indicates highly reduced NDVI values throughout the season, due to the severe drought.

Fig. 4c - NDVI - Jun 9th - Jun 25th 2005

Fig. 4c - NDVI versus the mean NDVI for this time step. Showing a worsening of drought conditions especially in southern Kenya. The highlighted blue box shows an affected corn growing region within the Eastern Province, and the highlighted red box shows an affected wheat growing region within the Western Province.

Fig. 4d - NDVI - Jun 9th - Jun 25th 2005

Fig. 4d - NDVI anomaly image: Jun 9th - Jun 25th 2005 versus the mean NDVI for this time-step between 2000 and 2004. The highlighted crop region in Castile-León shows highly reduced NDVI values. The red line consistently below the green line indicates highly reduced NDVI values throughout the season, due to the severe drought.

D. Enhanced Cropland Products using MODIS : A Dynamic Continuous Cropland Mask for use with MODIS time-series web interface

Continuous Cropland Mask functionality within MODIS

To successfully monitor worldwide agricultural regions and provide accurate agricultural crop production assessments, it is important to understand the spatial distribution of croplands. To do this, GLAM has developed a global croplands mask to identify all sites used for crop production.

Croplands are highly variable both temporally and spatially. Croplands vary from year to year due to events such as drought and fallow periods, and they vastly differ across the globe in accordance with characteristics such as cropping intensity and field size. A flexible crop likelihood mask is used to depict these varying characteristics of global crop cover.

This flexible croplands mask is generated by analysis of 4 years of MODIS data (2001-2004). Such a dynamic mask allows FAS analysts, through the MODIS time series web interface, to threshold cropland membership according to their needs and region of interest.

Regions featuring intensive agro-industrial farming practices such as the Maize Triangle in South Africa will have higher confidence values in the crop mask as compared to less intensively farmed regions in parts of Sub-Saharan Africa where crop identification is partly confounded with natural background vegetation phenologies. Thus, a customized threshold can be employed to examine areas of varying cropping intensification.

Fig. 4b - Zoom-in to crop growing region in Castile-León

Fig. 4b - Zoom-in to crop growing region in Castile-León showing NDVI anomalies for crop pixels.

Fig. 4c - NDVI - May 25th - June 9th 2005

Fig. 4c - NDVI histogram for the highlighted crop region for the May 25th - June 9th time-step for 2005 vs. 2004. The red histogram shows that the NDVI values for 2005 were significantly lower than the previous years.

Fig. 4d - NDVI - May 25th - June 9th 2005

Fig. 4d - NDVI anomaly image: May 25th - June 9th 2005 versus the mean NDVI for this time-step between 2000 and 2004. The highlighted crop region in Castile-León shows highly reduced NDVI values. The red line indicates highly reduced NDVI values throughout the season, due to the severe drought.

Fig. 4e - NDVI - May 25th - June 9th 2005

Fig. 4e - NDVI versus the mean NDVI for this time step. Showing a worsening of drought conditions especially in southern Kenya. The highlighted blue box shows an affected corn growing region within the Eastern Province, and the highlighted red box shows an affected wheat growing region within the Western Province.

Fig. 4f - NDVI - May 25th - June 9th 2005

Fig. 4f - NDVI anomaly image: May 25th - June 9th 2005 versus the mean NDVI for this time-step between 2000 and 2004. The highlighted crop region in Castile-León shows highly reduced NDVI values. The red line consistently below the green line indicates highly reduced NDVI values throughout the season, due to the severe drought.

Fig. 4g - NDVI - May 25th - June 9th 2005

Fig. 4g - NDVI versus the mean NDVI for this time step. Showing a worsening of drought conditions especially in southern Kenya. The highlighted blue box shows an affected corn growing region within the Eastern Province, and the highlighted red box shows an affected wheat growing region within the Western Province.

Fig. 4h - NDVI - May 25th - June 9th 2005

Fig. 4h - NDVI anomaly image: May 25th - June 9th 2005 versus the mean NDVI for this time-step between 2000 and 2004. The highlighted crop region in Castile-León shows highly reduced NDVI values. The red line indicates highly reduced NDVI values throughout the season, due to the severe drought.

Fig. 4i - NDVI - May 25th - June 9th 2005

Fig. 4i - NDVI versus the mean NDVI for this time step. Showing a worsening of drought conditions especially in southern Kenya. The highlighted blue box shows an affected corn growing region within the Eastern Province, and the highlighted red box shows an affected wheat growing region within the Western Province.

Fig. 4j - NDVI - May 25th - June 9th 2005

Fig. 4j - NDVI anomaly image: May 25th - June 9th 2005 versus the mean NDVI for this time-step between 2000 and 2004. The highlighted crop region in Castile-León shows highly reduced NDVI values. The red line consistently below the green line indicates highly reduced NDVI values throughout the season, due to the severe drought.

Fig. 4k - NDVI - May 25th - June 9th 2005

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